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BRIGHTNESS AND ~~[illegible]~~ CHROMA IN THE LIGHT OF THE PHYSICAL THEORY OF THE VISUAL PROCESS IN THE RETINA

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[Digest]

[Note: The theory of probability is employed to obtain ideal representations of brightness and ~~lightness~~ chroma, which are of importance in photometry.]

If a surface possesses in a definite direction the intensity K_λ of monochromatic radiation, then monochromatic brighness is $B_\lambda = V_\lambda K_\lambda d\lambda$, where V_λ a certain coefficient less than unity expresses the selective properties of the human eye.

The experiments of S. I. Vavilov and Ye. M. Brumberg show that the transformation of light energy reaching the retina into electrical oscillatory impulses, as observed by Hartlein and Granit in the fibers of the optic nerve, is connected directly with the absorption of photons by photoreactive molecules in the cones and rods; apparently for the formation of a single impulse, 4 to 8 photons must be absorbed by as many molecules, which become ions--the negative ones moving toward the primary synapsis and the positive ones moving, under the influence of the rather strong electrical field existing in the retina and nearby epithelial layer, to the walls of the external cells of the rods or cones. The mechanism governing the origin of impulses is still unknown.

Not every encounter of photon and photoreactive molecule is accompanied by such absorption. The number of "effective" photons equals $(n_e)_\lambda = p_\lambda \cdot n$ where n is the number of photons of frequency $v = c/\lambda$ occurring on the average per second in a cone and p_λ is the probability of a photon's absorption and resulting decay of a molecule. If a is the probability of encounter between an effective photon and any one of the N_o original photoreactive molecules in a cone, then the mean number of decompositions per second equals in the first approximation:

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$$H = an_eN = a'BN\sigma/f^2$$

where sigma σ is the area of pupil aperture, f is the first focal distance, $a' \approx 15500 \cdot a$ if B is in decimillistilbs.

The constant of ~~light~~ color sensation, or perception, is defined by the following ratios (invariable for small time intervals):

$$\mu_g = H_g/H_r = a_g n_{eg} N_g / a_r n_{er} N_r = m_g \cdot a_g N_g / a_r N_r$$

$$\mu_b = H_b/H_r = a_b n_{eb} N_b / a_r n_{er} N_r = m_b \cdot a_b N_b / a_r N_r$$

where n_{er}, n_{eg}, n_{eb} are the number of effective photons arising per second in modulators r, g, b ~~etc~~; N represents the concentration of photoreagents in a modulator for a given brighness B of a surface; a is probability of a ~~photo~~ photon-molecule encounter; and $m_g = n_{eg}/n_{er} = B_g/B_b$, $m_b = n_{eb}/n_{er} = B_b/B_r$, B_r, B_g, B_b being the components of brightness B, in accordance with spectral sensitivities of photoreagents in molecules and with given spectral composition of the radiation.

If two consecutive impulses passing through a nerve fiber are separated by a time interval not exceeding a certain tau τ, then these two impulses merge into one; tau τ is not constant, but decreases with increase in frequency. If a certain impulse from a primary ~~rod~~ cone "coincides" in the limits $\pm\tau$ with any one of the impulses from a secondary ~~rod~~ cone, then the probability of such a coincidence, or merging into one, is obviously $2\tau\nu$; but since not one but ν impulses pass per second from a primary cone the total probability of coincidence is $2\tau\nu^2$. All of these "coinciding" impulses are subtracted from the sum of frequencies; consequently, the resulting frequency ν' is

$$\nu' = 2\nu - 2\tau\nu^2 \cong 2\nu(1 - \tau\nu).$$

By similar reasoning, if a third is added to two primary rods, then the resulting frequency of impulses ν'' in the nerve fiber equals:

$$\nu'' = \nu'(1 - \tau\nu) + \nu(1 - \tau\nu').$$

It turns out that the previous quantities mu μ_g and μ_b cannot characterize completely the processes in nerve fibers, because of the increase

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in frequency of impulses in a nerve fiber serving a modulator group of cones in comparison with that which would be obtained from one cone. Hence we have the new ratios:

$$\mu'_g = a_g k_g n_{eg} N_g / a_r k_r n_{er} N_r = \mu_g \cdot k_g/k_r$$

$$\mu'_b = a_b k_b n_{eb} N_b / a_r k_r n_{er} N_r = \mu_b \cdot k_b/k_r$$

where the coefficients k_r, k_g, k_b characterize the increase in frequency.

Another ratio obtained is $N/N_0 = \beta k/(\beta k + an_e)$ where N_0 is the maximum number of photoreactive molecules ~~in dark~~ during adaptation to darkness; beta β is the rate of decomposition of unstable molecules forming in consequence of the inflow of "second-kind ions" from the epithelium to the cell; k is the ratio of the number of ions of the restorative agent to the number of second-kind ions in the ~~epithelium's~~ space charge of epithelium.

Since in the first approximation $a_g = a_r = a_b$ and also $\beta_g = \beta_r = \beta_b$ we have:

$$N_g/N_{0g} = \beta k/(\beta k + an_{eg}),\quad N_r/N_{0r} = \beta k/(\beta k + an_{er}).$$

Consequently, $\mu'_b = (k_g N_{0g}/k_r N_{0r}) \cdot m_g \cdot \dfrac{(1 + m_g)\beta k + an_e}{(1 + m_g)\beta k + m_g an_e}$

since $n_{er} = n_e/(1 + m_g)$ and $n_{eg} = m_g n_e/(1 + m_g)$ and setting $m_b = 0$.

Finally we obtain the quantity z_g determining the nature of ~~light~~ color sensation, or perception:

$$z_g = m \cdot \frac{(1 + m_g)\beta k + an_e}{(1 + m_g)\beta k + m_g an_e}$$

since $N_{0g}/N_{0r} = 1$ and $k_g/k_r \approx 1$.

Other important relations that are finally developed:

1. The formula expressing the establishment of sensation from the moment of darkness ($t = 0$) as a complicated function in t: $(\mu'_g)_t = f(t)$. At $t = 0$, $(\mu'_g)_0 = m_g \cdot k_g/k_r$; as t increases μ'_g approaches the limiting value $(\mu'_g)_\infty = z_g \cdot k_g/k_r$.
2. ~~Similarly~~ Similar expression for $(\mu'_b)_t$.
3. Improved formula ~~of~~ for H.

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